Tianjin University

Research Seminar

UC UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

Mobile Robots for Missions in Dynamical Natural Environments

XiaoQi Chen (陈小奇), PhD, Assoc Prof
Director, Mechatronics Engineering
Email: xqchen@canterbury.ac.nz

25 December 2008

New Zealand is located in the South Pacific between the Pacific Ocean and the Tasman Sea, between latitude 35 and 45 degrees south.

UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

Liveable Place

- In 1996, Christchurch was acknowledged as the outstanding garden city from 620 international entries.
- In 1997, Christchurch was judged Overall Winner of Major Cities in the Nations in Bloom International Competition to become 'Garden City of the World'!

“I think every person….. dreams of finding some enchanted place of beautiful mountains and breathtaking coastlines, clear lakes and amazing wildlife. Most people give up on it because they never get to New Zealand”

Mr. Bill Clinton – Former US President
Gala Dinner, Christchurch, NZ 2000


Dr XiaoQi Chen's Office
Dept of Mech Eng
University of Canterbury

Agenda

UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

- Overview of Mechatronics@UC
- Underwater Robot
- Wall Climbing Robot using Non-Contact Adhesion
- Invasion of Mobile Robots
- Conclusions

Who are involved

- Supervising Team:
  - Assoc Prof XiaoQi Chen (Director for Mechatronics) - robotics, mechatronic systems
  - Prof J Geoff Chase - dynamics and control, bioengineering, structural
  - Dr Wenhui Wang - robotics, bio-mechatronics
  - Dr Stefanie Gutschmidt - dynamics and vibration
  - Dept of Electrical Engineering, Computer Science, MacDiarmid, HITLab, Bioengineering Centre
- Technical Support
  - Mechatronics and electronics technicians: Rodney Elliot, Julian Murphy, Julian Philips,
  - Mechanical workshop
- Postgraduates
  - James Pinchin, PhD - Low-cost GPS based attitude solution using multiple software based receivers.
  - Patrick Wolm, MEng – Dynamic stability control of front wheel drive wheelchairs.
  - Scott Green, PhD - Human Robot Collaboration Utilising Augmented Reality
  - Ali Ghanbari, PhD – MEMS actuation and precision micromanipulation.
  - Mostafa Nayyerloo, PhD, – Structural health monitoring
  - Chris Hardie, MEng – biologically inspired robots
  - Matthew Keir, PhD – Head motion tracking, graduated in 2008
- Visiting Researchers / Fellows
  - Prof Richard King, Oregon Institute of Technology, Jun 2006 – Mar 2007
  - Prof Clarence de Silva, University of British Colombia, 1-31 August 2008
  - Australian DEST Endeavour Fellowship, Mr Ben Horan, Aug – Dec 2008. Haptics technology
- Interns
  - Julien Dufeu, Institut Francais de Mecanique Avancee (IFMA), 2007. Modelling of wall climbing device
  - Matthias Wagner, the University of Munich, 2007. Design of wall climbing robot.
  - Nikolas Schaal, The University of Stuttgart, 2007. Design of underwater vehicle.
  - Richard Engelaar, Eindhoven University of Technology, 2008. underwater vehicle.
  - Johan Vervoort, Eindhoven University of Technology, 2008. underwater vehicle.
  - Harald Zophoniasson, ENISE, France, 2008. High-precision motorised stage
- Industrial Collaborators
  - Geospatial Research Centre, Dynamic Controls Limited, Industrial Research Limited (IRL), Commtest, etc.

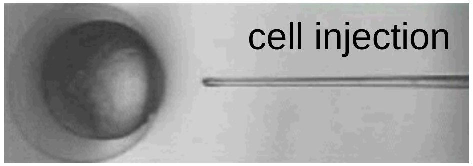
Mechatronics@UC

Bio-mechatronics

- Assistive devices for rehabilitation
- Bio-micromanipulation – cell injection

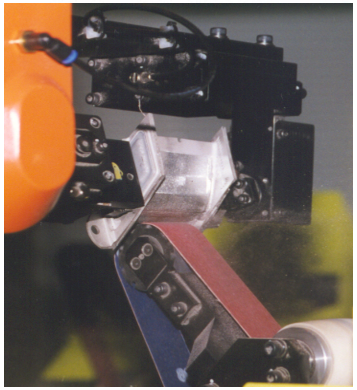
Burwood Academy *of* Independent Living

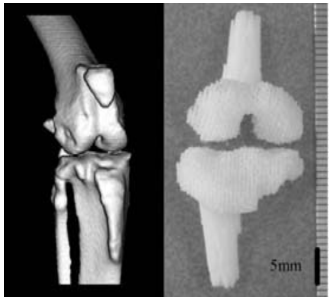
INDUSTRIAL RESEARCH LIMITED



Instrumentation and Automation

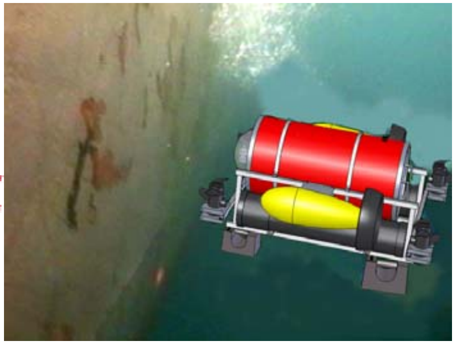
- Manufacturing
- Structural control
- Energy harvesting
- Bio-scaffolding





NIWA
Taihoro Nukurangi

HITLabNZ



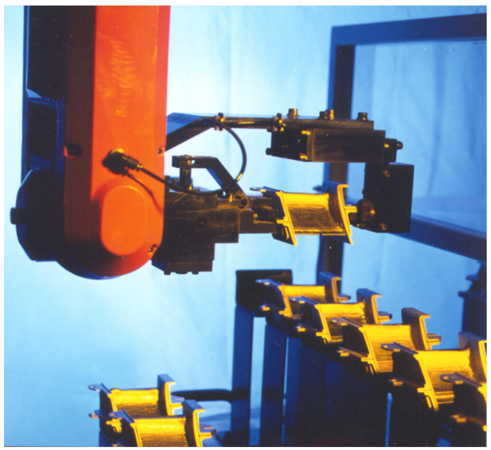
Geospatial
Research Centre

Mobile Robotics

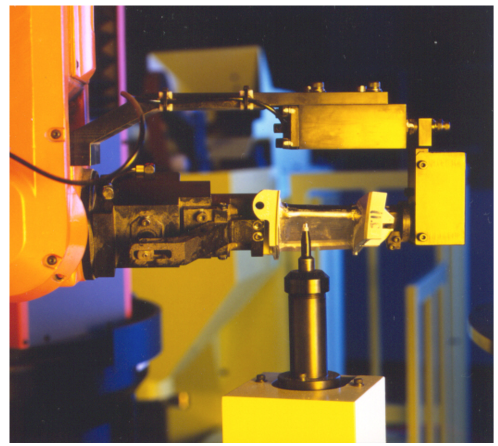
- Unmanned aerial vehicle, micro air vehicle
- Underwater vehicle for bio-security inspection
- Wall-climb robot for tank welding

SMART: *S*elf-compliance, *M*ulti-tasking, *A*daptive-planning, *R*e-configurable, *T*eaching-free

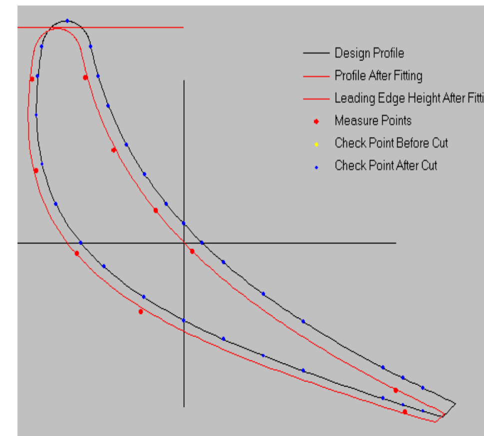
Video Clip



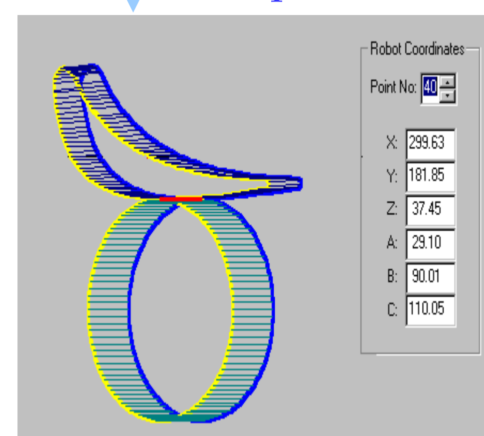
Part Loading



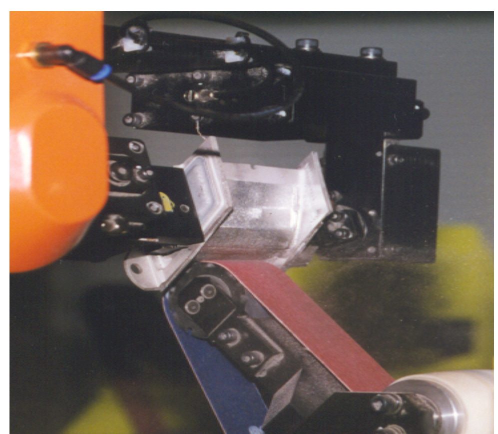
Airfoil Measurement



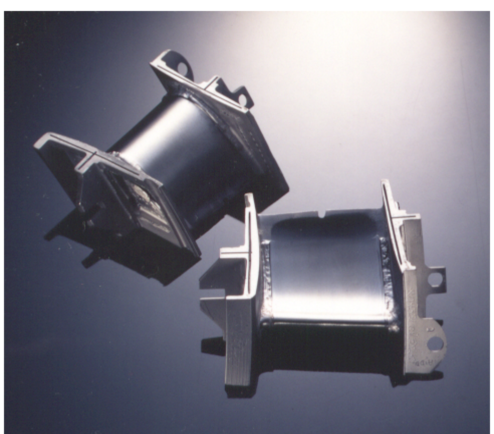
Distortion Compensation



Path Generation



Auto Blending

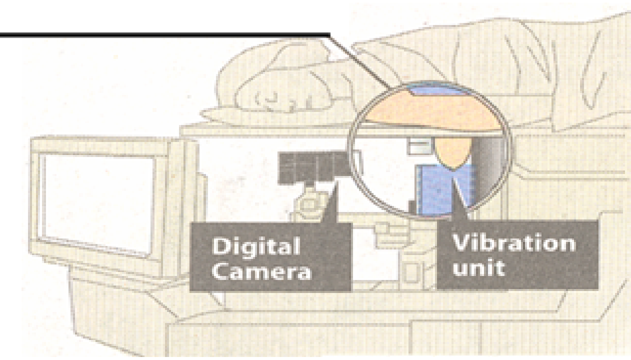


Blended Airfoil

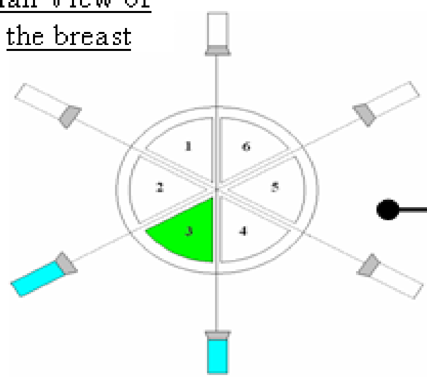
Digital Image-Based Elasto-Tomography

The DIET system is broken down into 4 fundamental steps: (1) Actuation → (2) Image Capture → (3) Motion Tracking and measurement → (4) Tissue stiffness reconstruction

1. A woman's breast is vibrated by an actuator and imaged with high-resolution digital cameras.

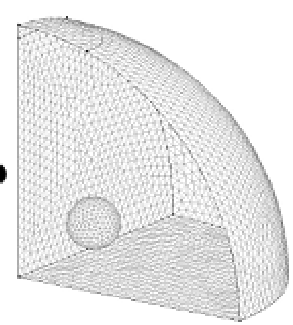


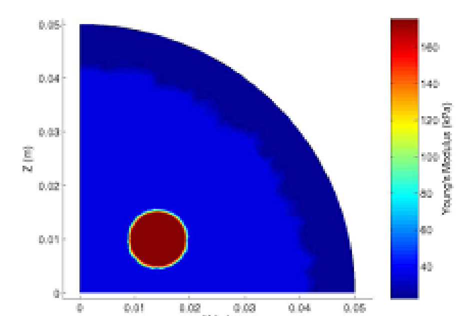
Plan View of the breast



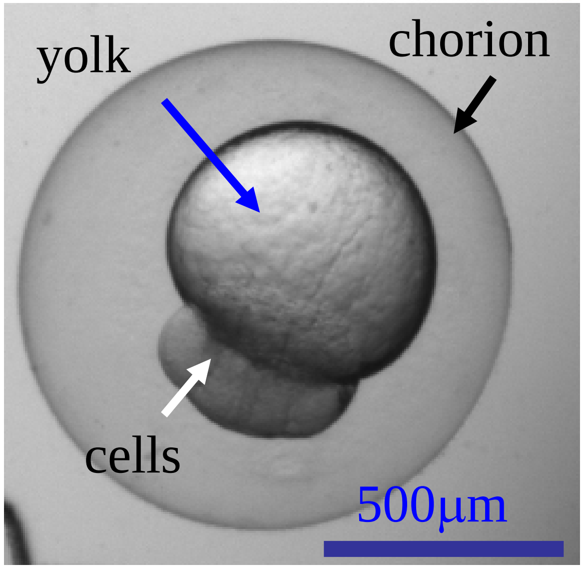
2. Spatially calibrated digital cameras combined with a motion sensor measures the surface motion of the breast.

3. Finite Element method converts the measured breast surface motion into a 3-D stiffness distribution, where regions of high stiffness suggest cancer.

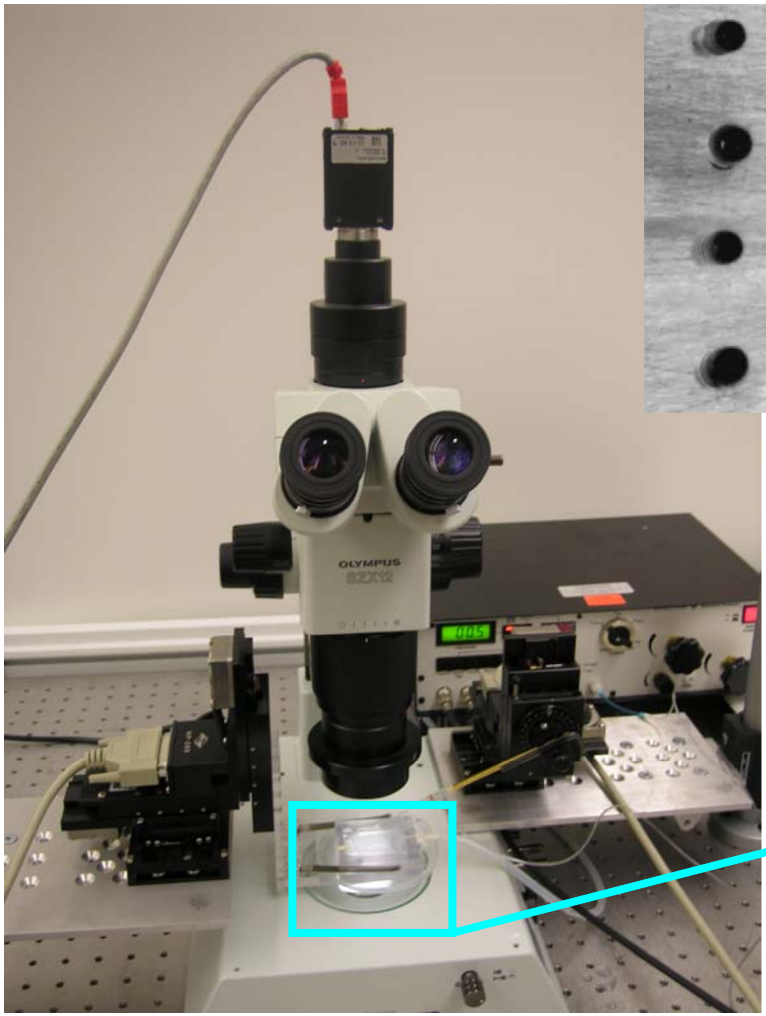


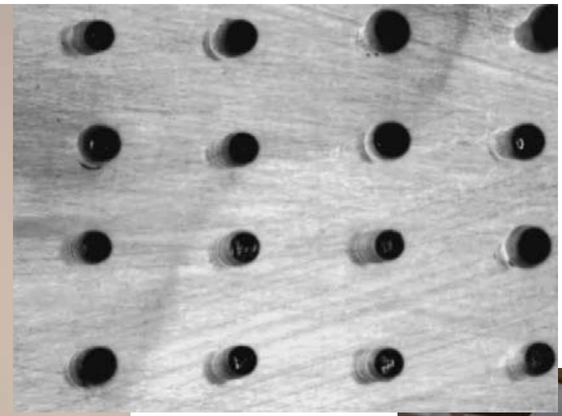


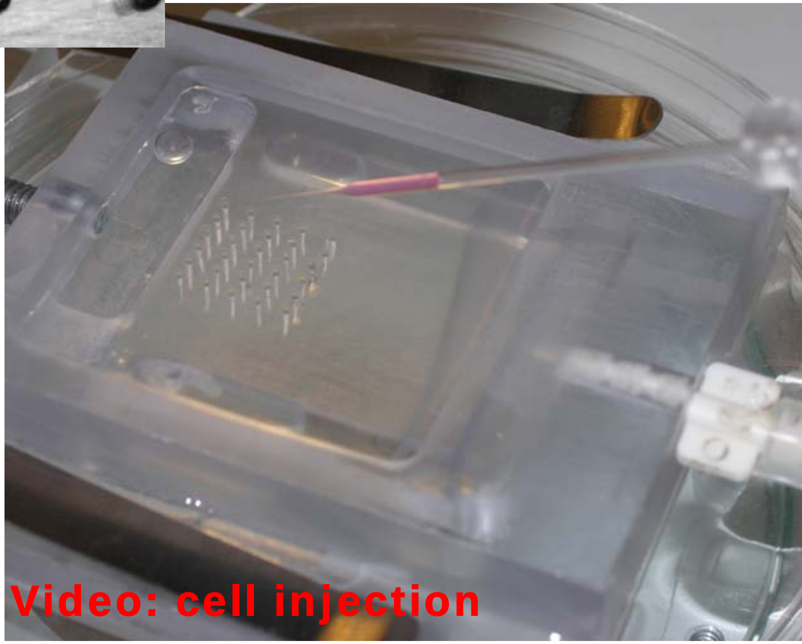
Microrobotic Cell Injection



Video: cell preparation

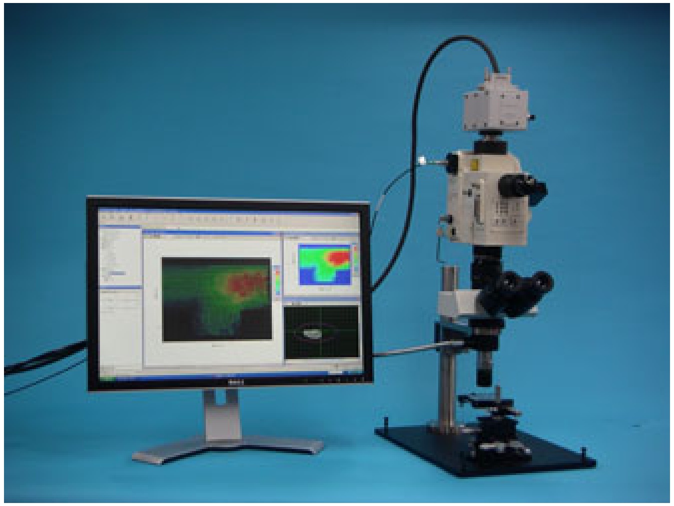


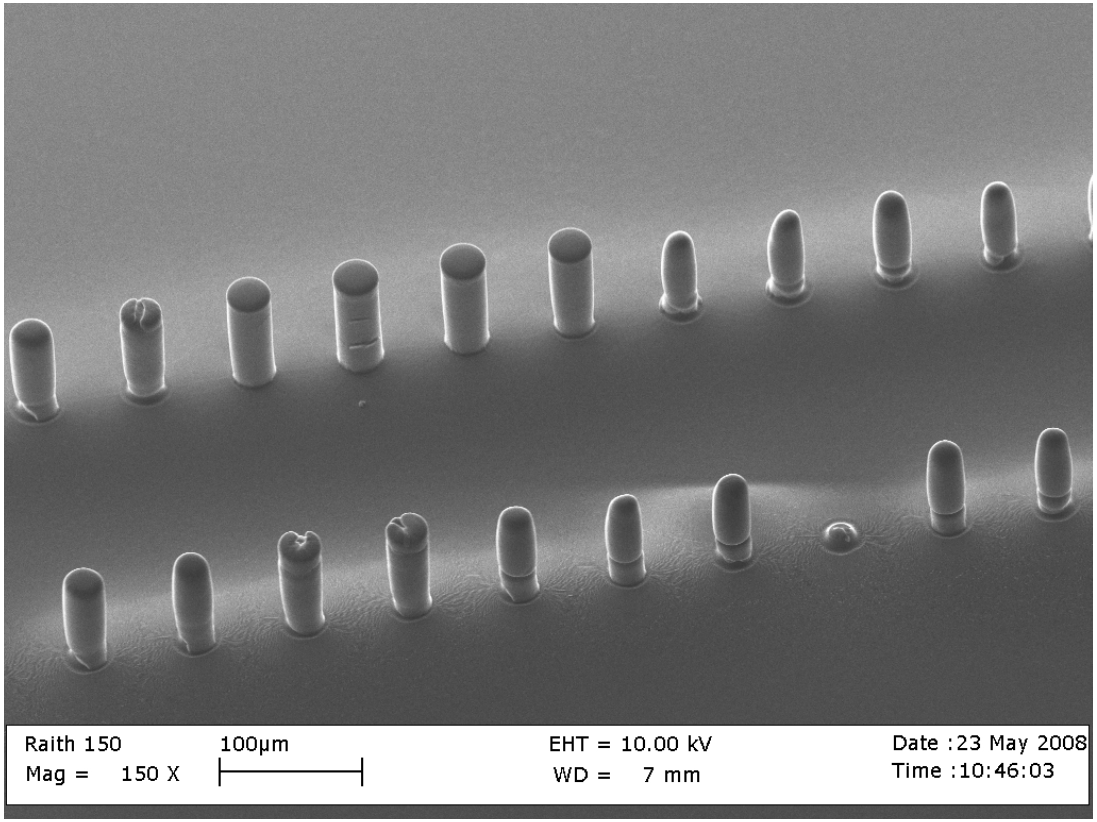


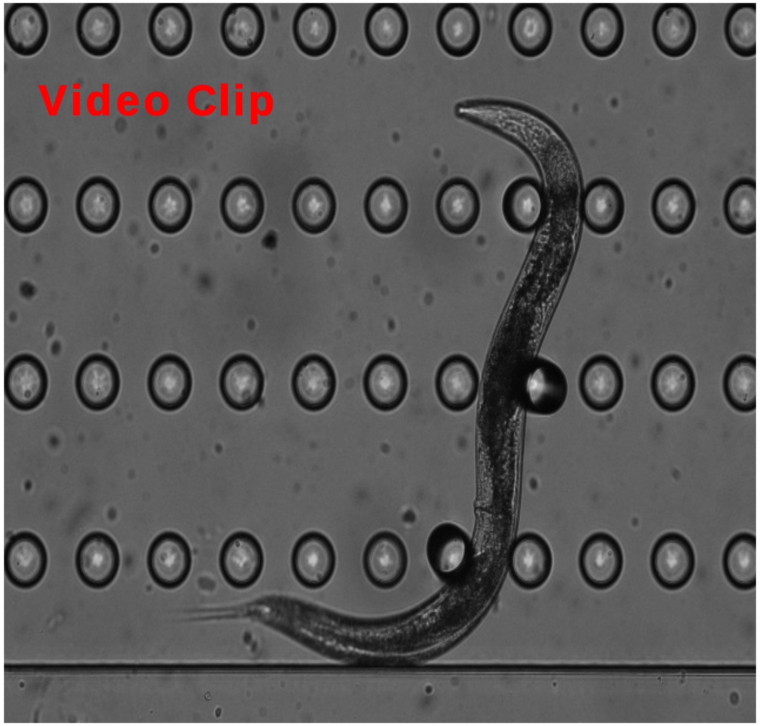


W.H. Wang, D. Hewitt, C.E. Hann, J.G. Chase, and X.Q. Chen, "Application of machine vision for automated cell injection", Special Issue on: "Advanced Intelligent Mechatronics and Manufacturing Systems" , International Journal of Mechatronics and Manufacturing Systems.

Biomimetics - Force measurement of C. elegans in motion

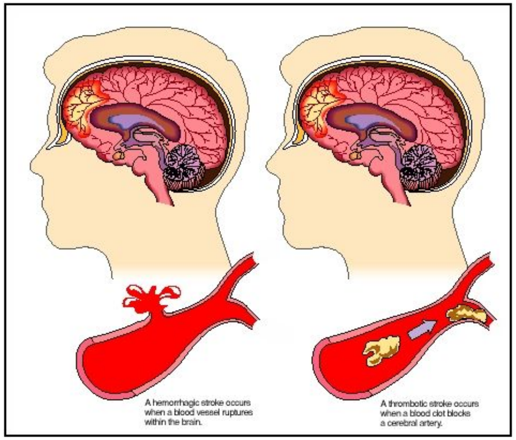


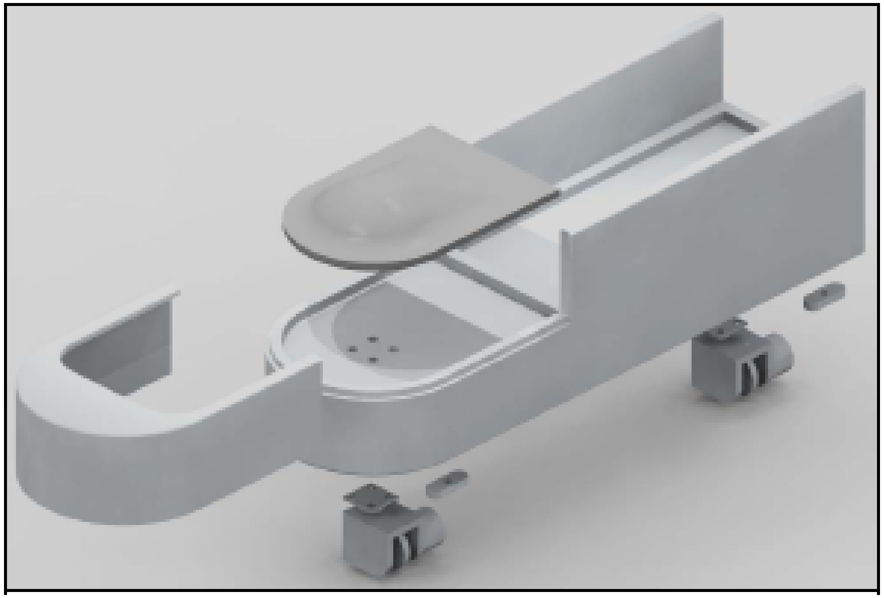




Ali Ghanbari, Volker Nock, Wenhui Wang, Richard Blaikie, J. Geoffrey Chase, XiaoQi Chen, and Christopher E. Hann (2008). “Force Pattern Characterization of C. elegans in Motion”, 15th Intl Conf on Mechatronics and Machine Vision in Practice (M2VIP), Auckland, New Zealand, Dec 2-4,CD-ROM, 6-pages.

Variable Resistance Rehabilitation Device

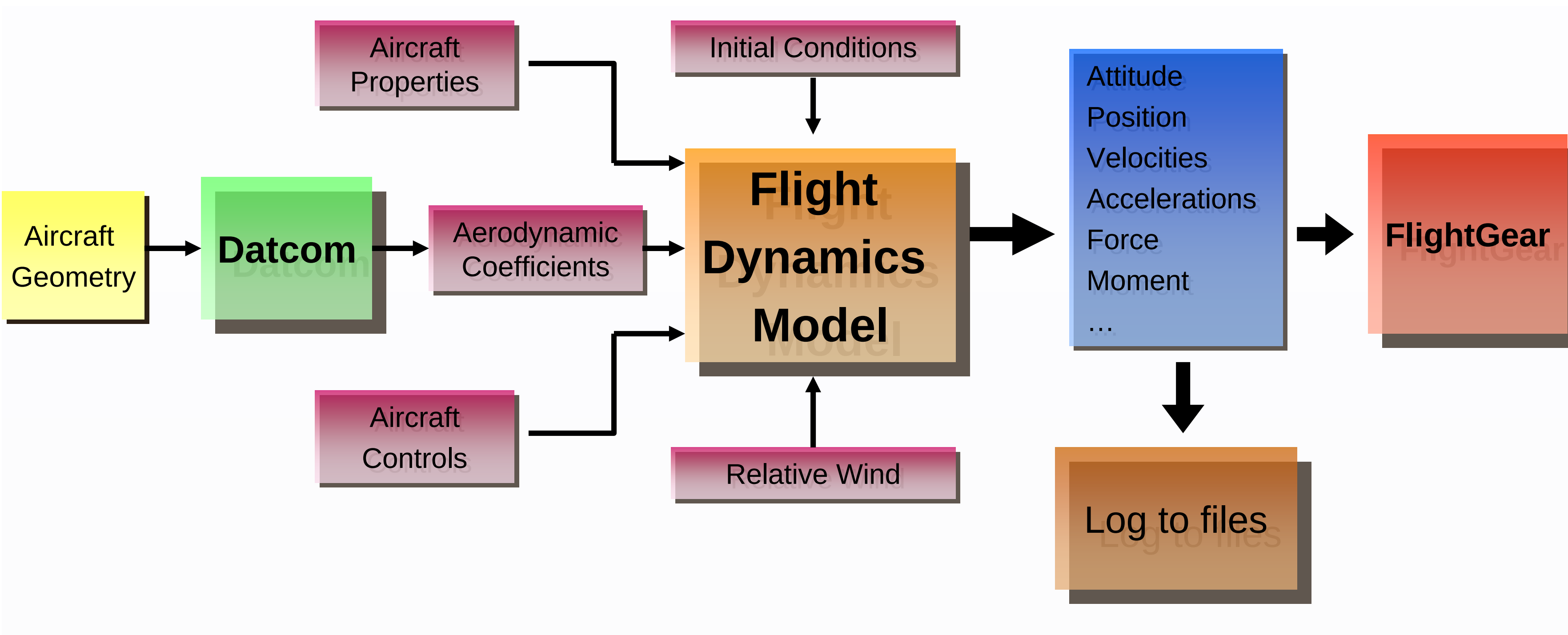




Provisional Patent (2008)

Integrated Flight Dynamics Model

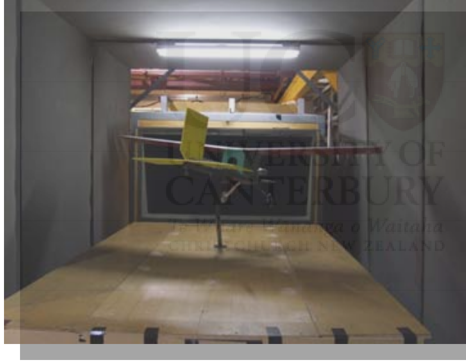
- The input of aircraft geometry instead of aerodynamic coefficients greatly simplified aircraft model development
  - No wind tunnel testing is required
  - Effects on changing aircraft geometry can be seen immediately
  - Much better repeatability

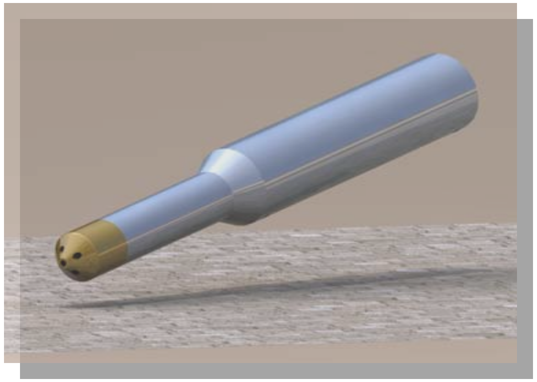


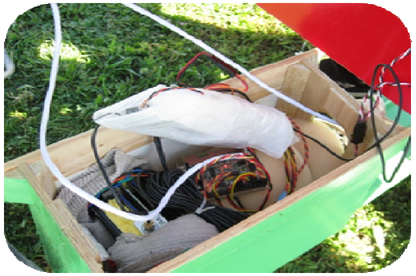
Q. Ou, X.Q. Chen, D. Park, A. Marburg, and J. Pinchin (2008), "Integrated Flight Dynamics Modelling for Unmanned Aerial Vehicles". Proc 2008 ASME/IEEE International Conference on Mechatronic and Embedded Systems (MESA08), Part of ASME International Design Technical Conf (DETCON), Beijing, China, October 12-15.

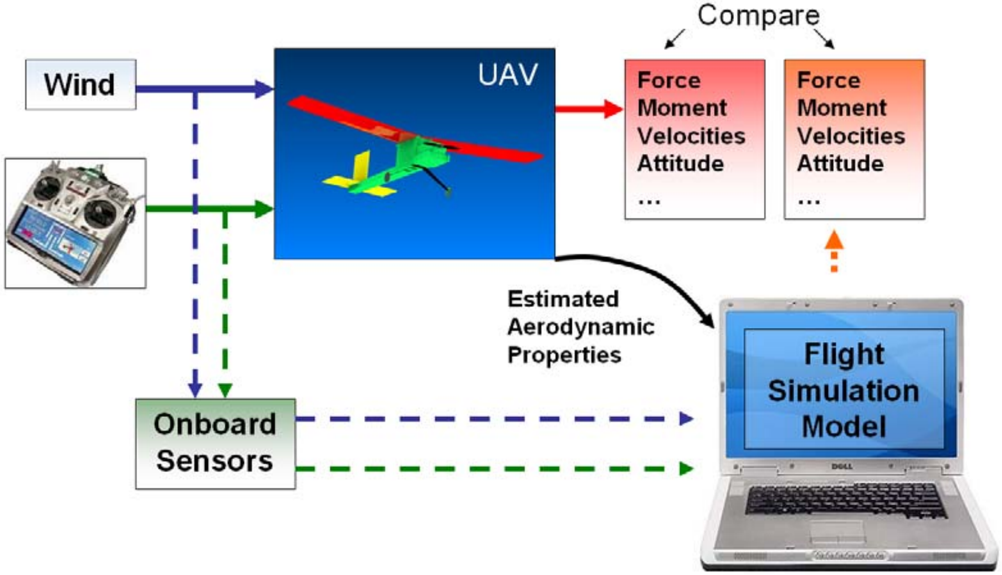
FDM Validation with On-Board Instruments

- Equipment used
  - 2.4 meter wing-span gas powered RC plane
  - GPS base station
  - Inertia navigation system
  - Servo pulse acquisition device
  - Wind speed sensor
  - Data logger
  - Wind tunnel









Video: UAV Test

Back

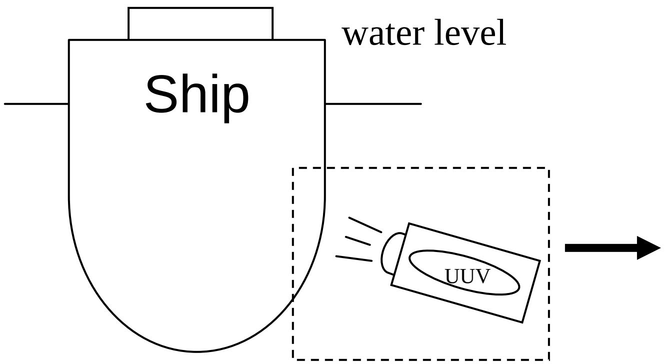
D. R. Wong, Q. Ou, M. Sinclair, Y. J. Li, X. Q. Chen, A. Marburg (2008). **"Unmanned Aerial Vehicle Flight Model Validation Using On-Board Sensing and Instrumentation", 15**th Intl Conf on Mechatronics and Machine Vision in Practice (M2VIP), Auckland, New Zealand, Dec 2-4, CD-ROM.

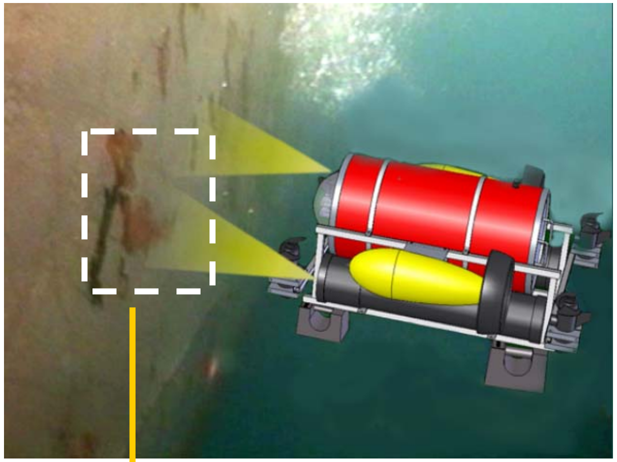
Underwater Robots for Shallow Water Applications

W.H. Wang, R.C. Engelaar, X.Q. Chen & J.G. Chase, "The State-of-Art of Underwater Vehicles – Theories and Applications" *Mobile Robots - State of the Art in Land, Sea, Air, and Collaborative Missions*, Editors: X.Q. Chen, Y.Q. Chen, and J.G Chasse, ISBN 978-3-902613-39-4, I-Tech Education and Publishing, Vienna, Austria. (In press).

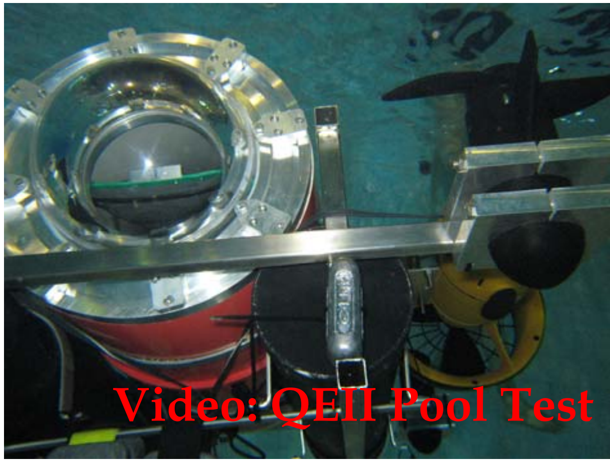
Canterbury UUV - Biosecurity

For shallow waters, up to 20m depth

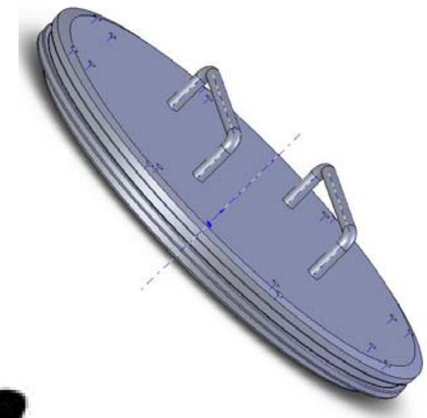


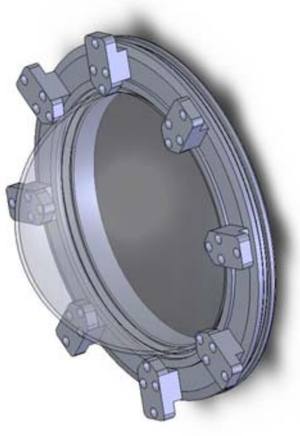


sea chest



Hull design

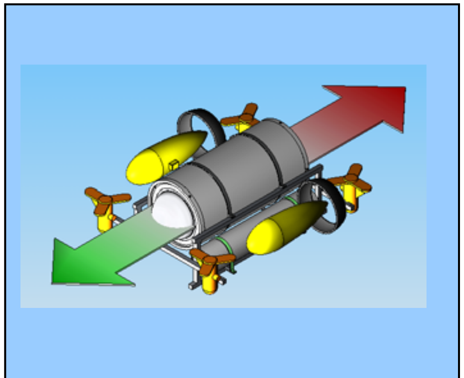




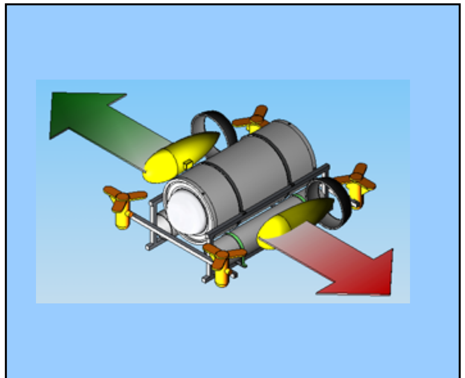
PVC storm water pipe

A cylinder has favourable geometry for both pressure (no obvious stress concentrations) and dynamic reasons (minimum drag).

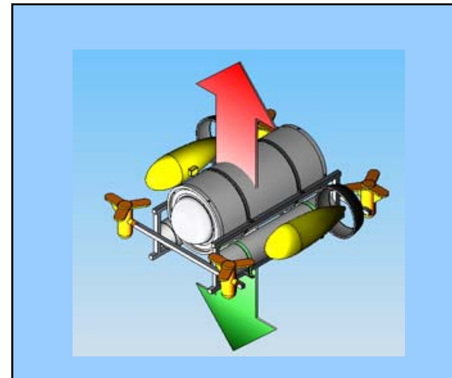
Propulsion and steering



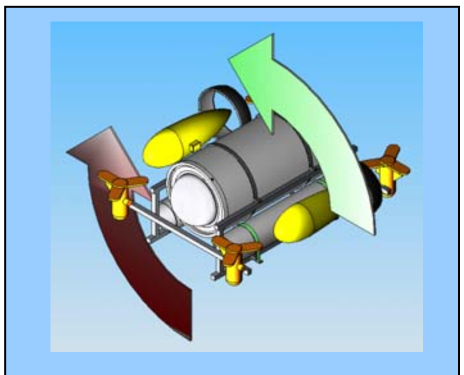
surge - u



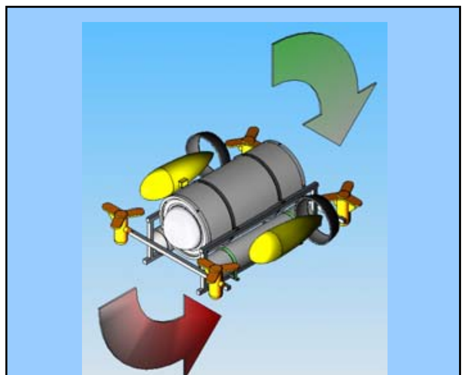
sway - y



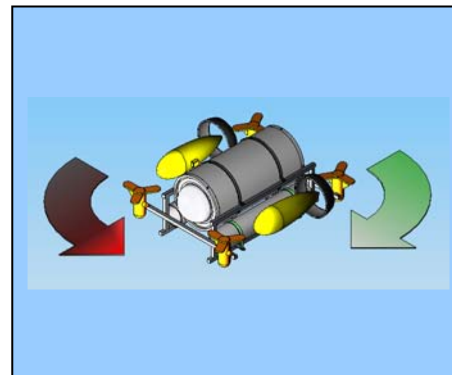
heave - z



roll - p



pitch - q

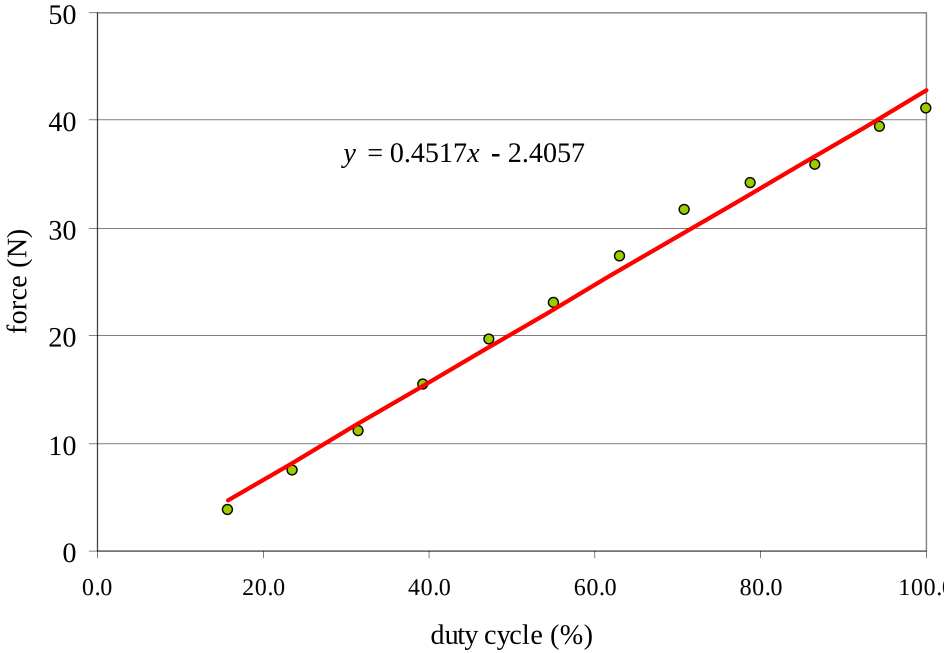


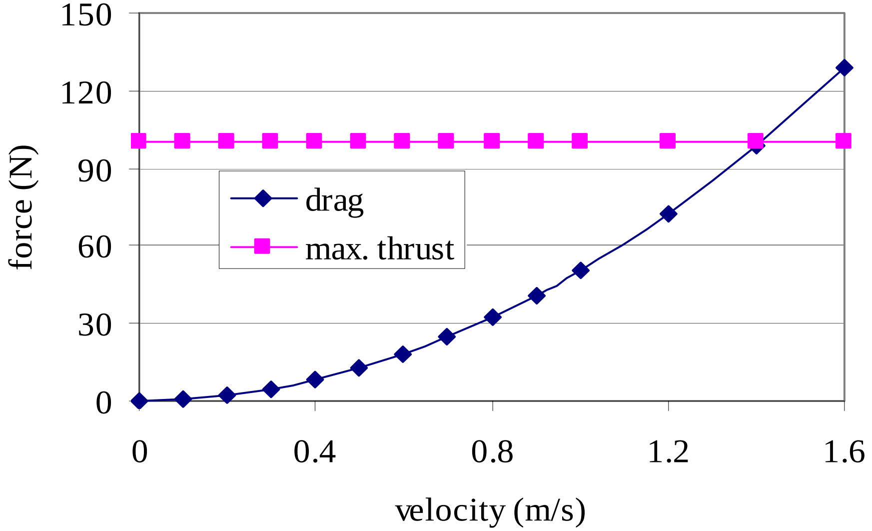
yaw - r

Dive scooter

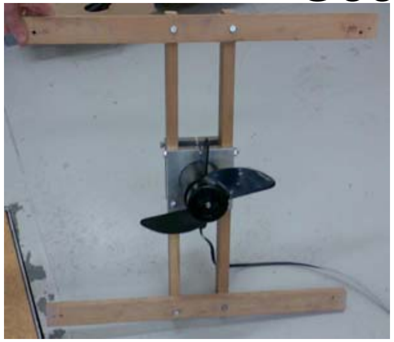
Vol: 12V
Max. F: 5kg
Depth: 20m
Price: US$60

Thrusting





Good linearity



Test rig

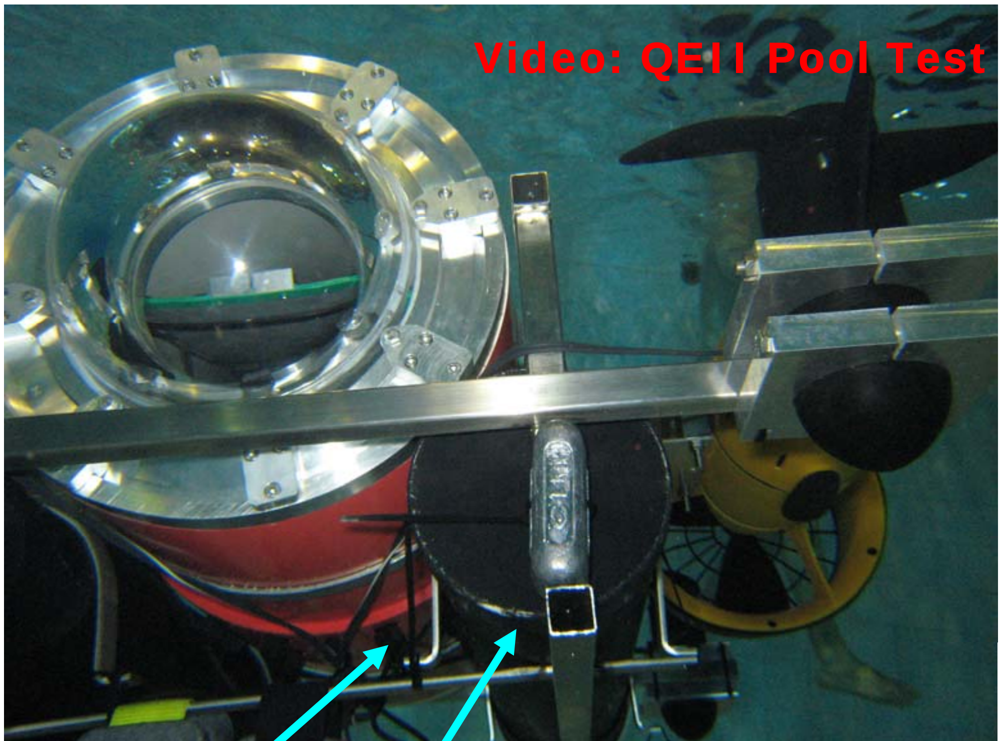
Drag force:

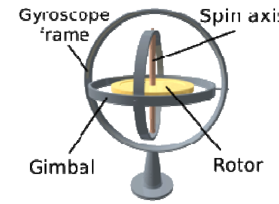
$F_{drag} = 1/2 \cdot \rho \cdot v^2 \cdot c_d \cdot S$

Ansys modelig and simulation

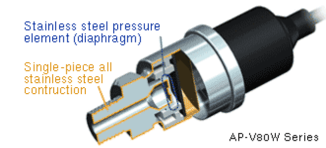
Max. velocity: 1.4m/s

Vehicle design and electronics



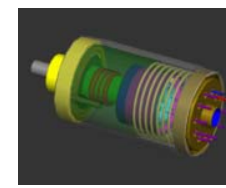


IMU



Pressure sensor-depth

Webcam



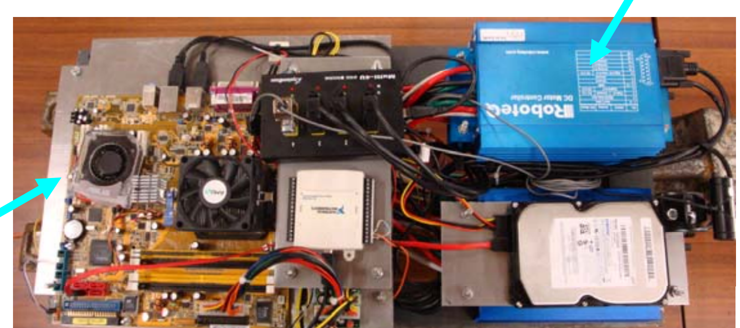
Temperature sensor

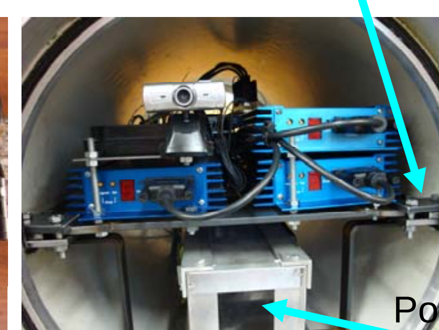
cable and canister seals

RoboteQ motor controller

Sliding mechanism

Mother board





Power supply

Back

A Novel Wall Climbing Robot using Non-Contact Adhesion

ScienceAlert
Australia & New Zealand

Home | News | Features | Opinions | Events | Jobs

Wall-climbing robot breakthrough

Sunday, 19 August 2007

University of Canterbury

Robotic research at the University of Canterbury has climbed new heights with the development of a wall-climbing robot.

The robot has been developed by a team of researchers lead by Associate Professor XiaoQi Chen in the University's Mechanical Engineering department.

UC UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

- **Motivation**
- **The Bernoulli Effect**
- **Design Considerations**
- **Perforamce**

BIOMIMICRY NEWS

Recent News | Archives | Tags | About | Newsletter | Submit News | Links | Subscribe

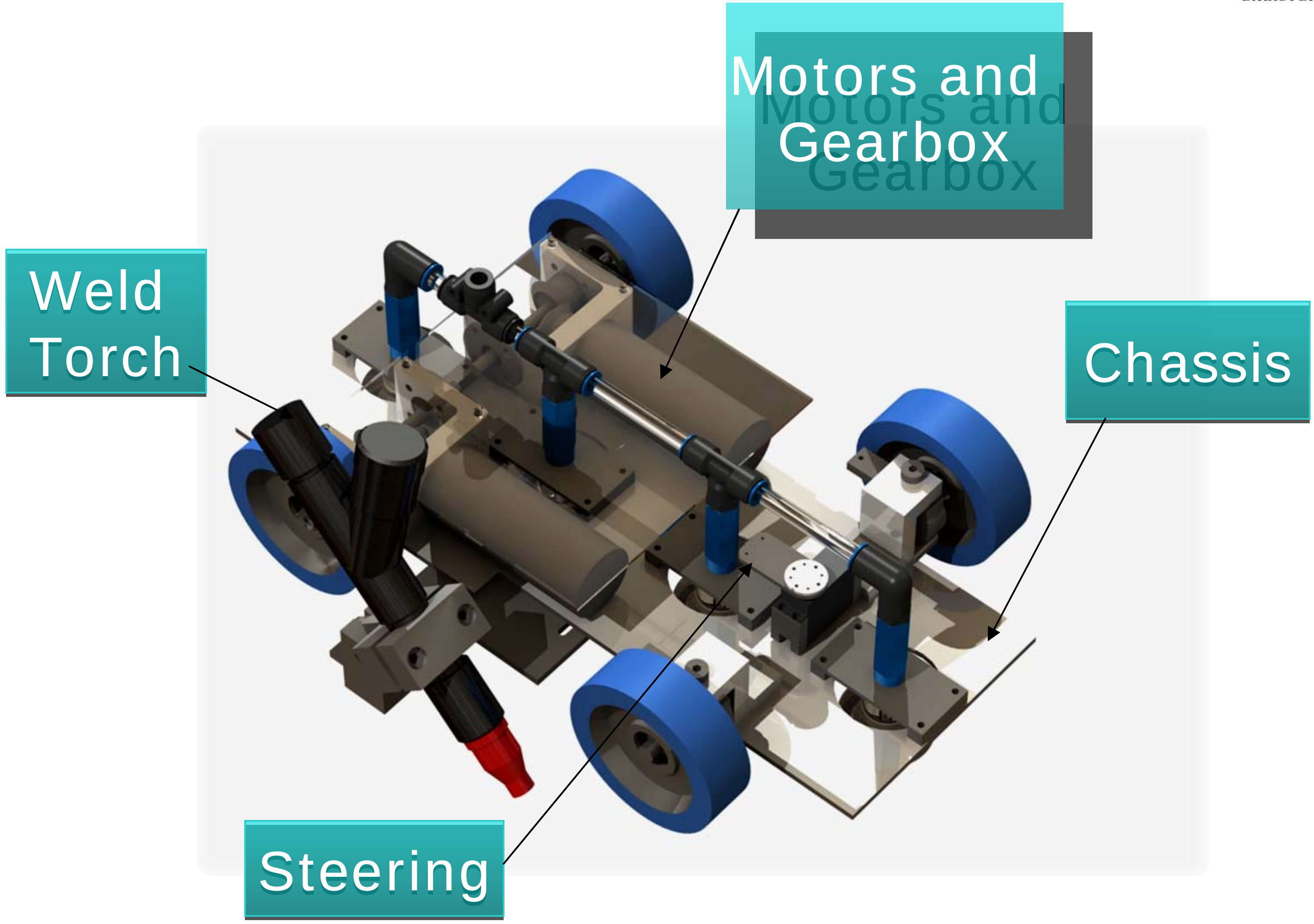
Engineers design robot capable of climbing walls (8/21/2007)

M. Wagner, X.Q. Chen, W.H. Wang, and J.G. Chase (2008), "A novel wall climbing device based on Bernoulli effect", Proc 2008 IEEE/ASME International Conference on Mechatronic and Embedded Systems and Applications (MESA08), ISBN: 978-1-4244-2368-2, Beijing, China, October 12-15, pp. 210-215. (Best Student Paper Award).

The Problem – Tank Welding

- Adhere Vertically
- Track a Seam to +/-0.5mm
- Produce Welds to Industry Standard
- Perform at twice the Existing Weld Rate

Wall Climbing Welding Robot using Vacuum Suction



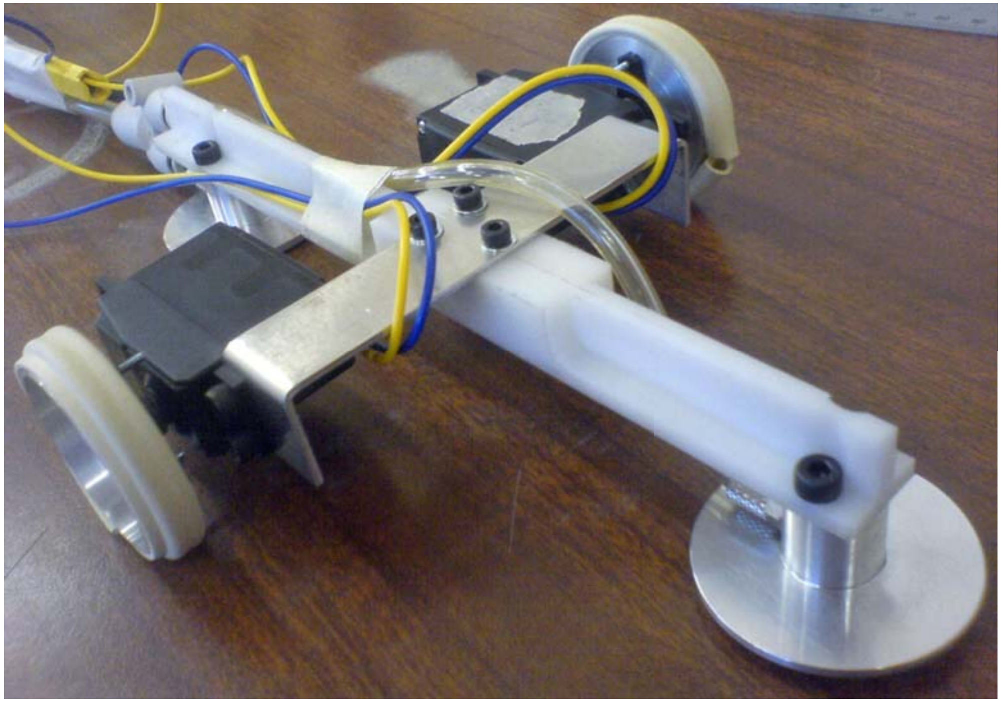
Motivation

Adhesion		Surface Conditions
Magnetic	→	Ferromagnetic
Vacuum	→	Smooth, Non-permeable
Microfibre	→	Clean

Adhesion effect independent of materials and surface conditions is desirable

Challenge

Develop a Wall Climbing robot insensible to surface conditions
Adhesion device using air pressure to create attraction force



The Bernoulli Effect

Assumptions to simplify equations:

Laminar, steady, frictionless flow, viscous effects are neglected, incompressible fluid, only forces acting are pressure and weight

$$\frac{v^2}{2} + \frac{p}{\rho} + gh = const$$

Bernoulli equation:

$$\frac{v_1^{\ 2}}{2} + \frac{p_1}{\rho} + gh_1 = \frac{v_2^{\ 2}}{2} + \frac{p_2}{\rho} + gh_2$$

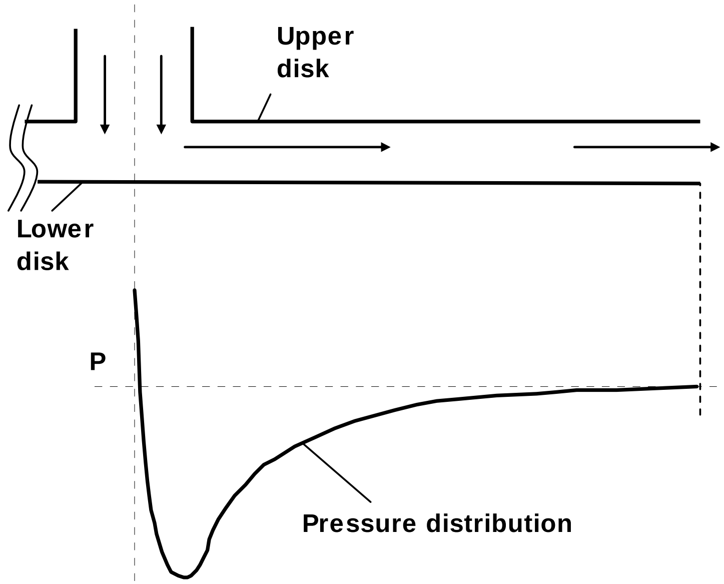
The Bernoulli Effect (Bernoulli‘s Principle):

$$\rho \frac{v^2}{2} + p = const$$

The pressure decreases with a simultaneously increasing velocity

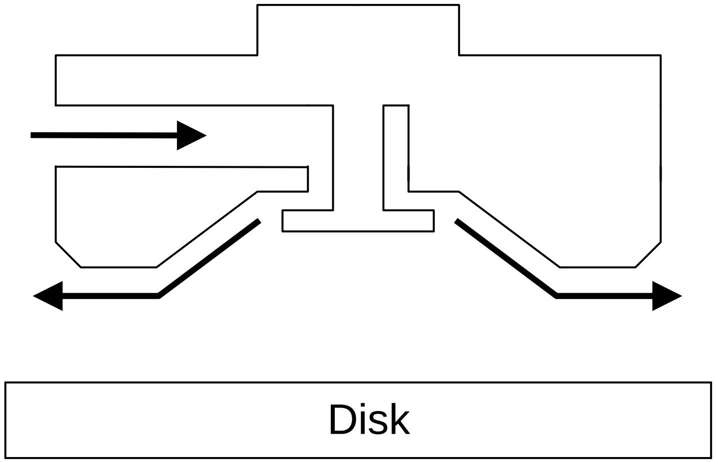
Design Considerations

Existing Devices



• Very small attraction force

NCT device



• Heavy
• High flow rate

More efficient lightweight device is needed

The Final Bernoulli Pad

Material: Aluminium

Number of parts: 2

Undercut: 0.5mm

Nozzle gap: 0.10mm

Diameter: 45mm

Height: 18mm

Total weight: 19g

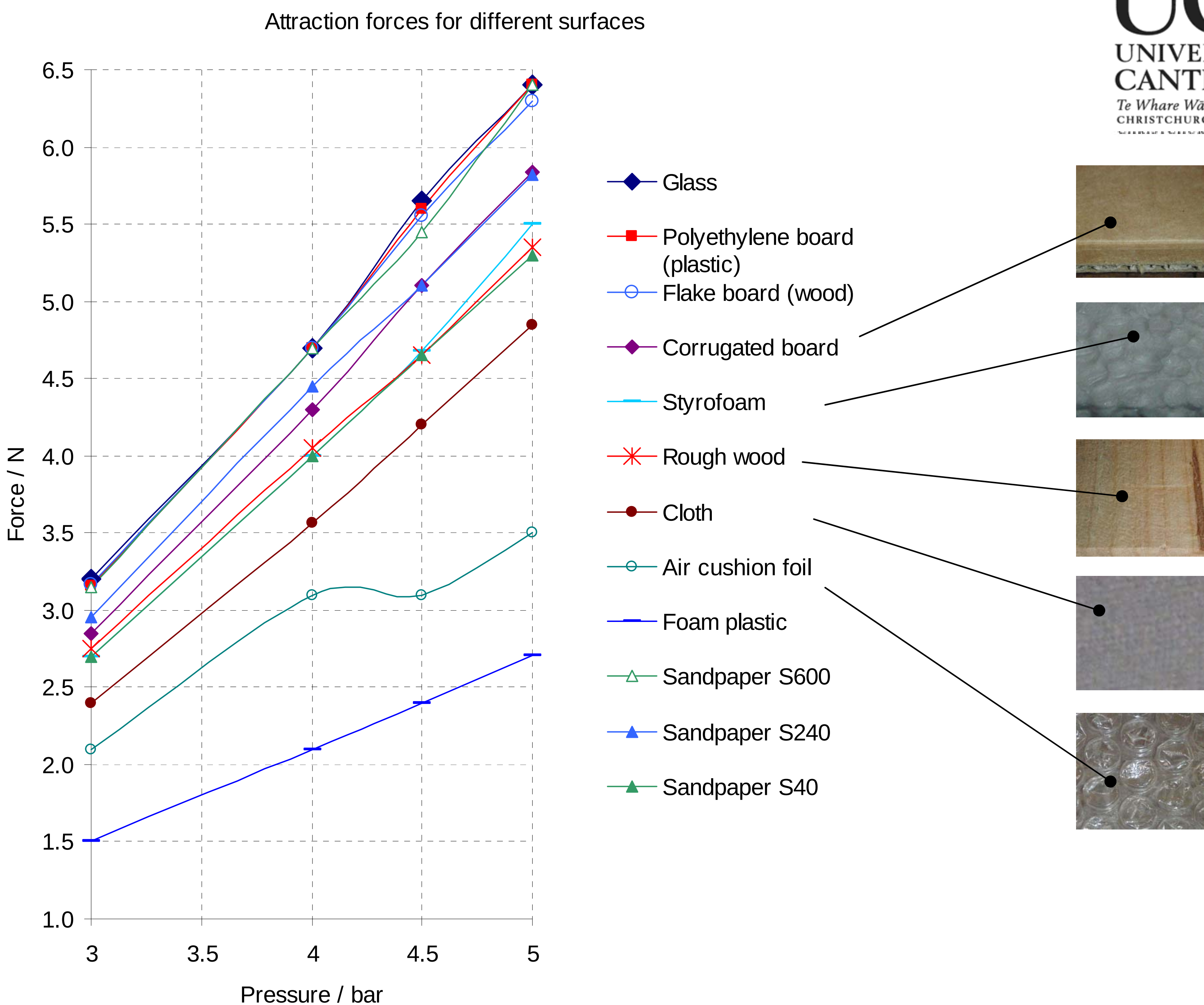
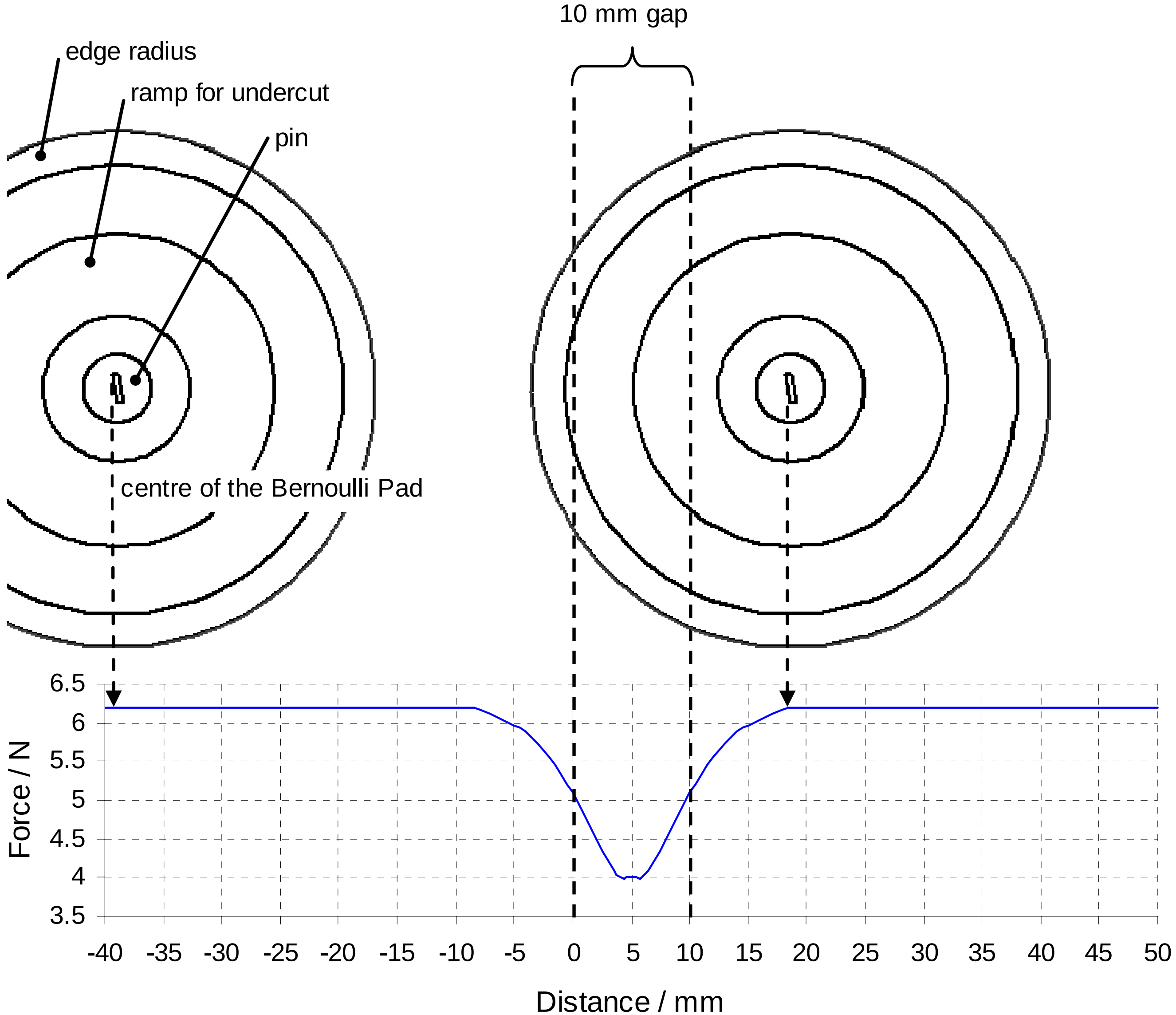
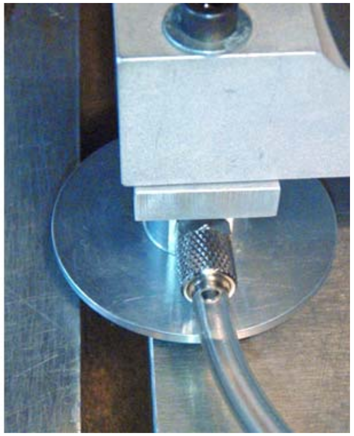
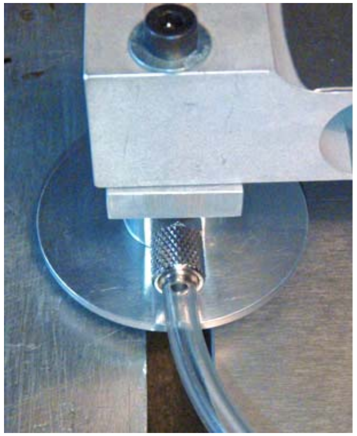

Attraction forces for different surfaces
Force / N
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
3
3.5
4
4.5
5
Pressure / bar
Glass
Polyethylene board (plastic)
Flake board (wood)
Corrugated board
Styrofoam
Rough wood
Cloth
Air cushion foil
Foam plastic
Sandpaper S600
Sandpaper S240
Sandpaper S40

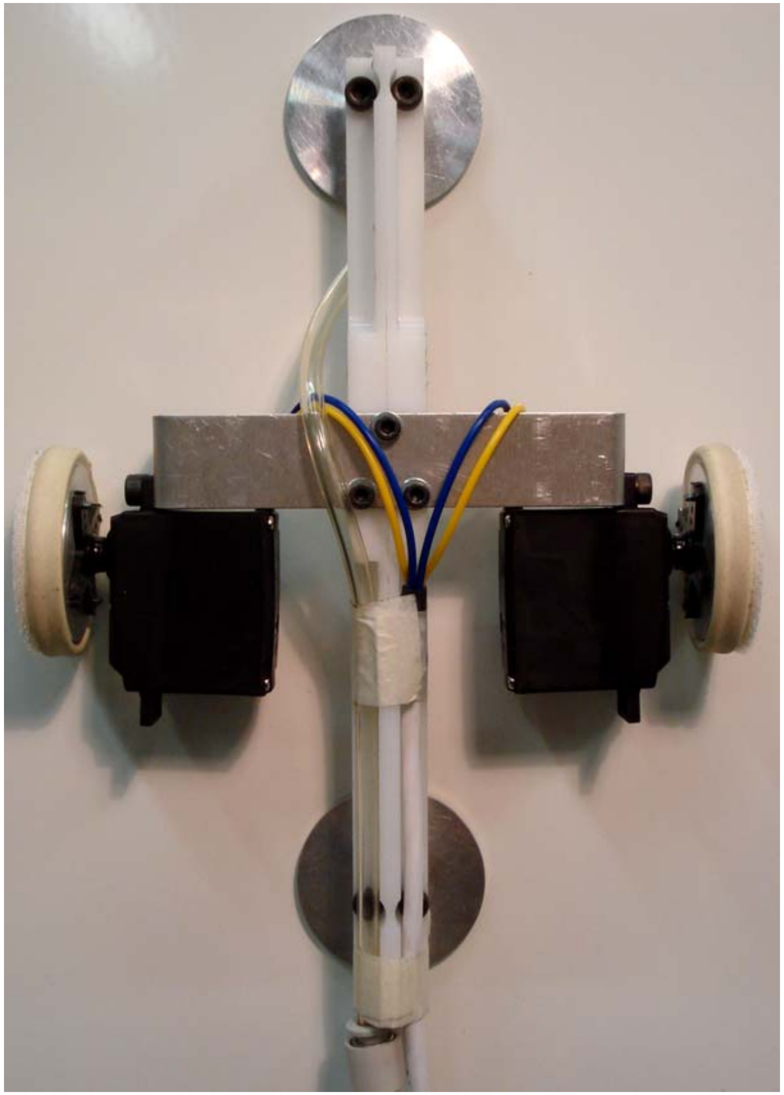
Illustration of passing a 10mm gap







The Prototype Robot



Parts:

1 Plastic as main body

2 Bernoulli Pads

1 Aluminium suspension beam

2 Servo drive trains

2 Aluminium wheels with high friction tires (friction coefficient 0.74 on glass)

UC Wall-Climbing Robot - Performace

Total weight: 234g
Max attraction force (at 5 bar): 12N

Additional weight that can be lifted (on a wall as on a ceiling): 500g

The robot is able to transverse the gaps on the wall

High manoeuvrability in every direction, and on different surfaces.

Video: Climbing different surfaces and ceiling

Back

Invasion of Mobile Robots

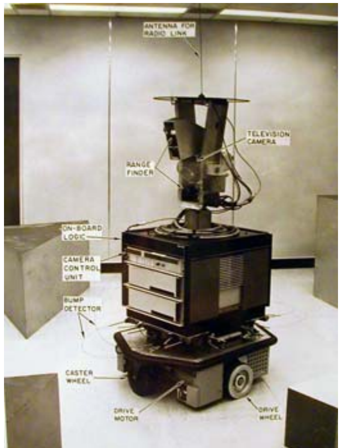
Mobile Robots - State of the Art in Land, Sea, Air, and Collaborative Missions, Editors: X.Q. Chen, Y.Q. Chen, and J.G Chasse, ISBN 978-3-902613-39-4, I-Tech Education and Publishing, Vienna, Austria. (In press).

A short history of robots

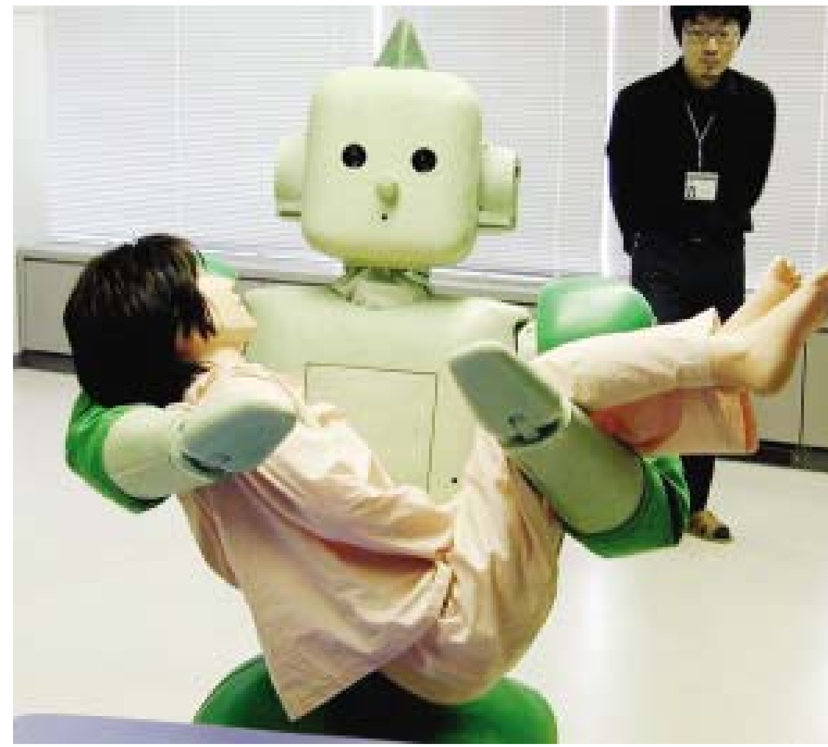
- **1921** - The term "robot" was first used in a play called "R.U.R." or "Rossum's Universal Robots" by the Czech writer Karel Capek. The plot was simple: man makes robot then robot kills man!
- **1941** - Science fiction writer Isaac Asimov first used the word "robotics" to describe the technology of robots and predicted the rise of a powerful robot industry.
- **1956** - George Devol and Joseph Engelberger formed the world's first robot company.
- **1961** - The first industrial robot was deployed in a General Motors automobile factory in New Jersey. It was called UNIMATE.
- **1963** - The first artificial robotic arm to be controlled by a computer was designed. The Rancho Arm was designed as a tool for the handicapped and it's six joints gave it the flexibility of a human arm.
- **1968** - The octopus-like Tentacle Arm was developed by Marvin Minsky.
- **1969** - The Stanford Arm was the first electrically powered, computer-controlled robot arm.
- **1970** - Shakey was introduced as the first mobile robot controlled by artificial intelligence. It was produced by SRI International.
- **1974** - A robotic arm (the Silver Arm) that performed small-parts assembly using feedback from touch and pressure sensors was designed.
- **1979** - The Standford Cart crossed a chair-filled room without human assistance.

Explosion of Mobile Robotics

- Unmanned Aerial Vehicle, flying robots
- Unmanned Underwater Robots
- Climbing and walking robots, rescue robots
- Animal-inspired robots: pets, cockroach, gecko, fish
- Humanoid robots
- Agricultural robots: plough, sowing, harvesting



Into Hospital



Into Fields

•Global positioning system (GPS) to autonomously navigate agricultural machineries on the field
•Imaging sensors recognise crops, fruits, plants, etc

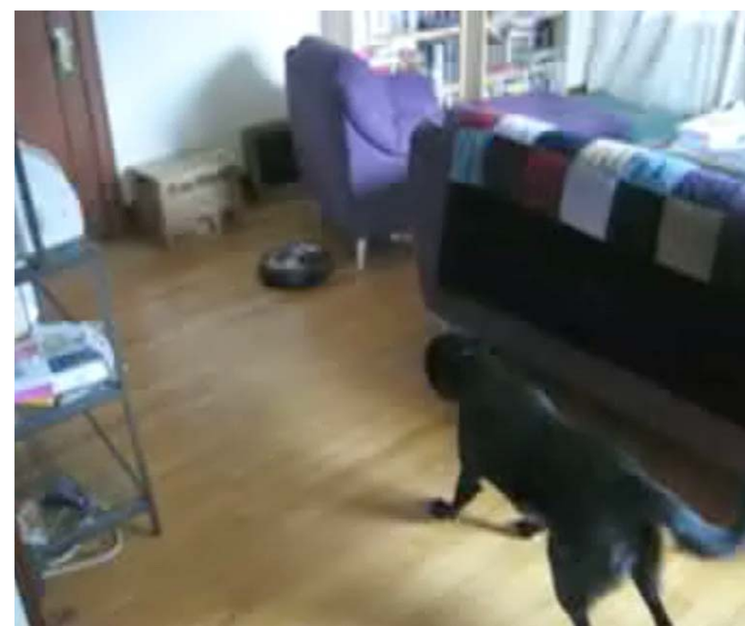
Into Sea

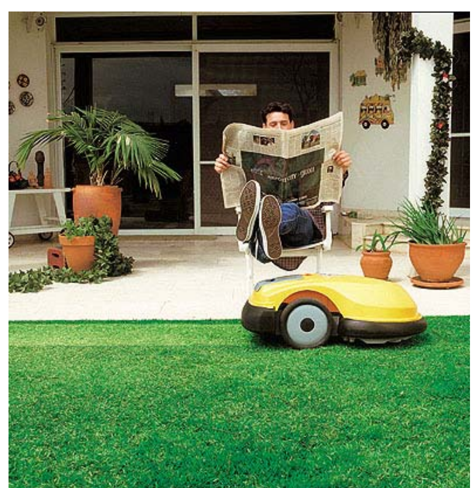
UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

- Oceanographic exploration, environmental monitoring, surveying, undersea operations, and military mission.
- Scientists often use these underwater vehicles to map the ocean floor, conduct fish counts, and monitor pollution.

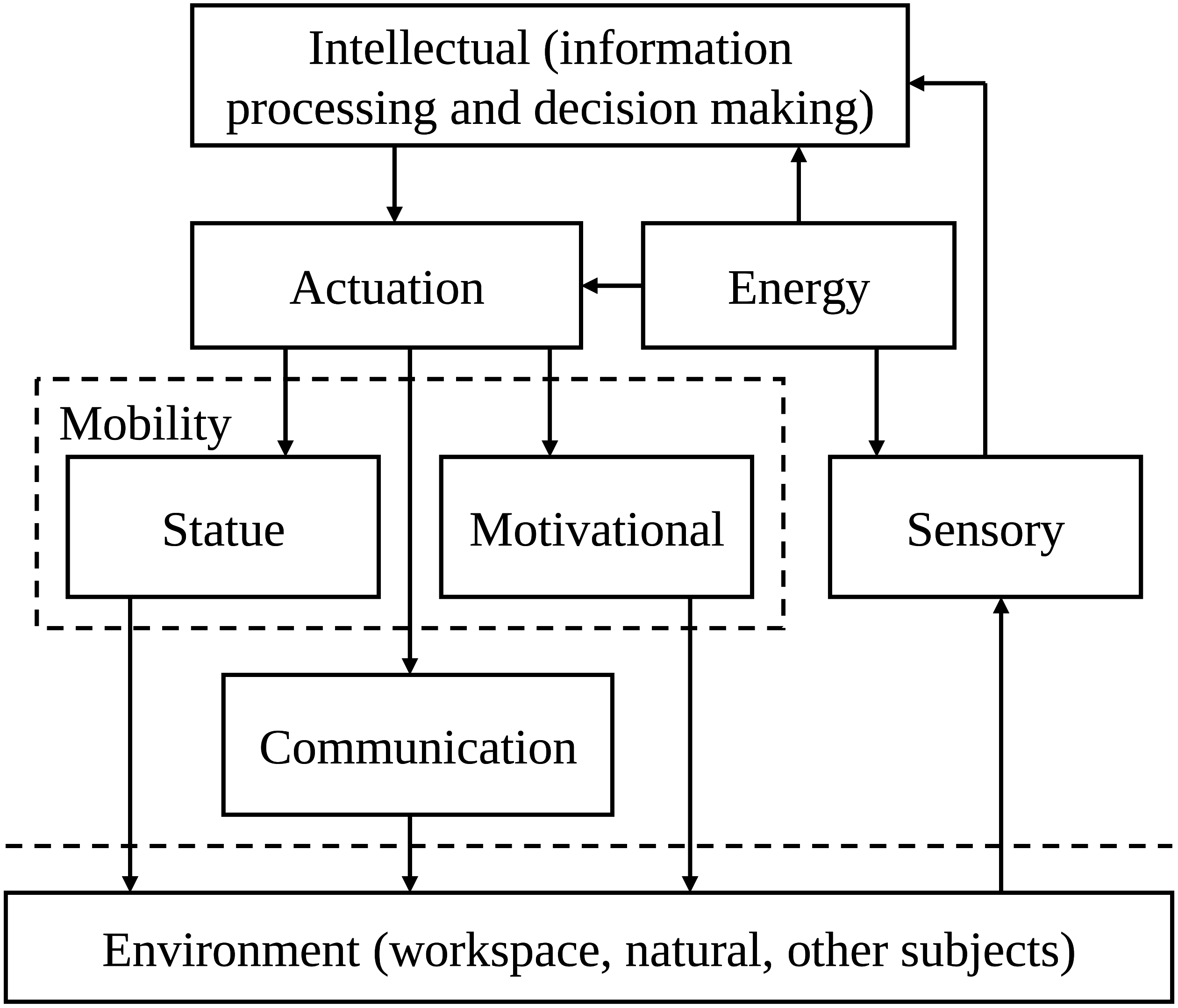
Into Our Homes
- Members of family?

- Free us from home chores: vacuuming floor, mowing lawn.
- Robot butler.
- Robot assistant for elderly, handicapped.
- Patrolling, security.





Functional model of generalised robots



Comparison of functional modules between robots and human beings

Functional Blocks	Human Beings	Robots
Intellectual	Brain	Microprocessor (computer hardware and software)
Statue	Skeleton	Mechanical frame (airframe, chassis, hull).
Motivational	Limbs	Wheels, legs, tracks, propellers, grippers, etc.
Actuation	Muscles	Hydraulic, electric, pneumatic. piezoelectric, electrostatic actuators; artificial muscles.
Sensory (perception)	Eyes, ears, skin	Cameras, optic sensors, sonar, sound, infra-red light, magnetic fields, radiation, etc.
Communication	Speech, gesture	Data, image/video, sound
Energy	Food / energy storage	Power source / energy storage.

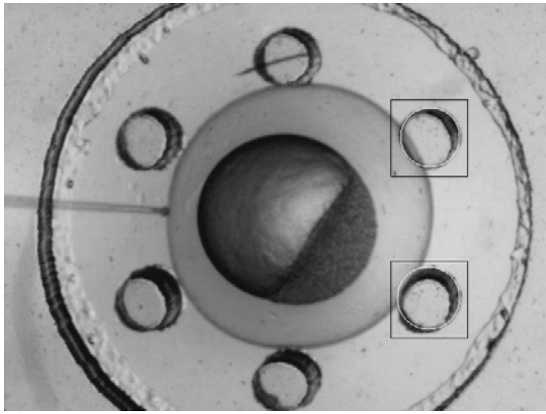
Comparison of lifting capacity between robots and human

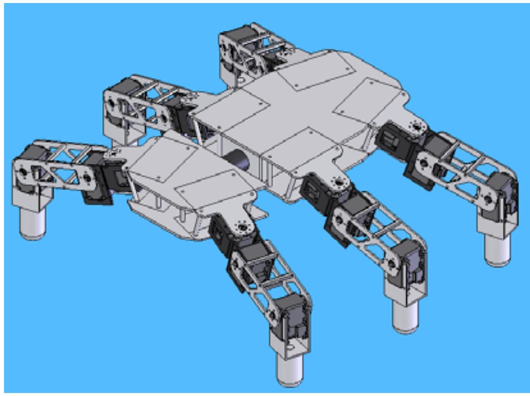
	Self weight (Kg)	Lifting capacity (Kg)	Lifting-to-weight ratio
ABB IRB 2000	350	10	~0.03
Honda Asimo	52	1 (for two hands)	~0.02
2008 Olympic Women 53 Kg Weightlifting Gold	53	126 (clean & jerk)	~2.4
A person having similar weight to Asimo	52	~ 20	~0.4

Conclusion

- Technologies are maturing to tackle complex process automation
  - ➢ Machining under uncertain conditions
  - ➢ Additive manufacturing
  - ➢ Welding, etc.
- Future automation moves towards
  - ➢ Connectivitty
  - ➢ Modularity
  - ➢ Portability / interchangeability

  (Microsoft expends into robotics)
- Emerging research areas in robotics
  - ➢ Service robotics
  - ➢ Biologically inspired robots
  - ➢ Human machine interface technology: augmented reality, brain-computer interface





Service Robots – a disruptive technology

National Intelligence Council, "Disruptive Civil Technologies: Six Technologies with Potential Impacts on US Interests out to 2025", Conference Report, April 2008

- Robots have the potential to replace humans in a variety of applications with far-reaching implications.
- The use of unmanned systems for terrorist activities could emerge because the availability of commercial civil robot platforms will increase significantly.
- Unmanned military systems with a much greater level of autonomy and closely related/synergistic technologies (e.g. human augmentation systems) could enhance the performance of soldiers.
- The development and implementation of robots for elder-care applications, and the development of human-augmentation technologies, mean that robots could be working alongside humans in looking after and rehabilitating people. A change in domestic and social responsibilities and a change in domestic employment requirements could adversely affect lower income service-oriented workers.

Can mobile robotics emulate the impact of PC?